Quirky Dark Matter

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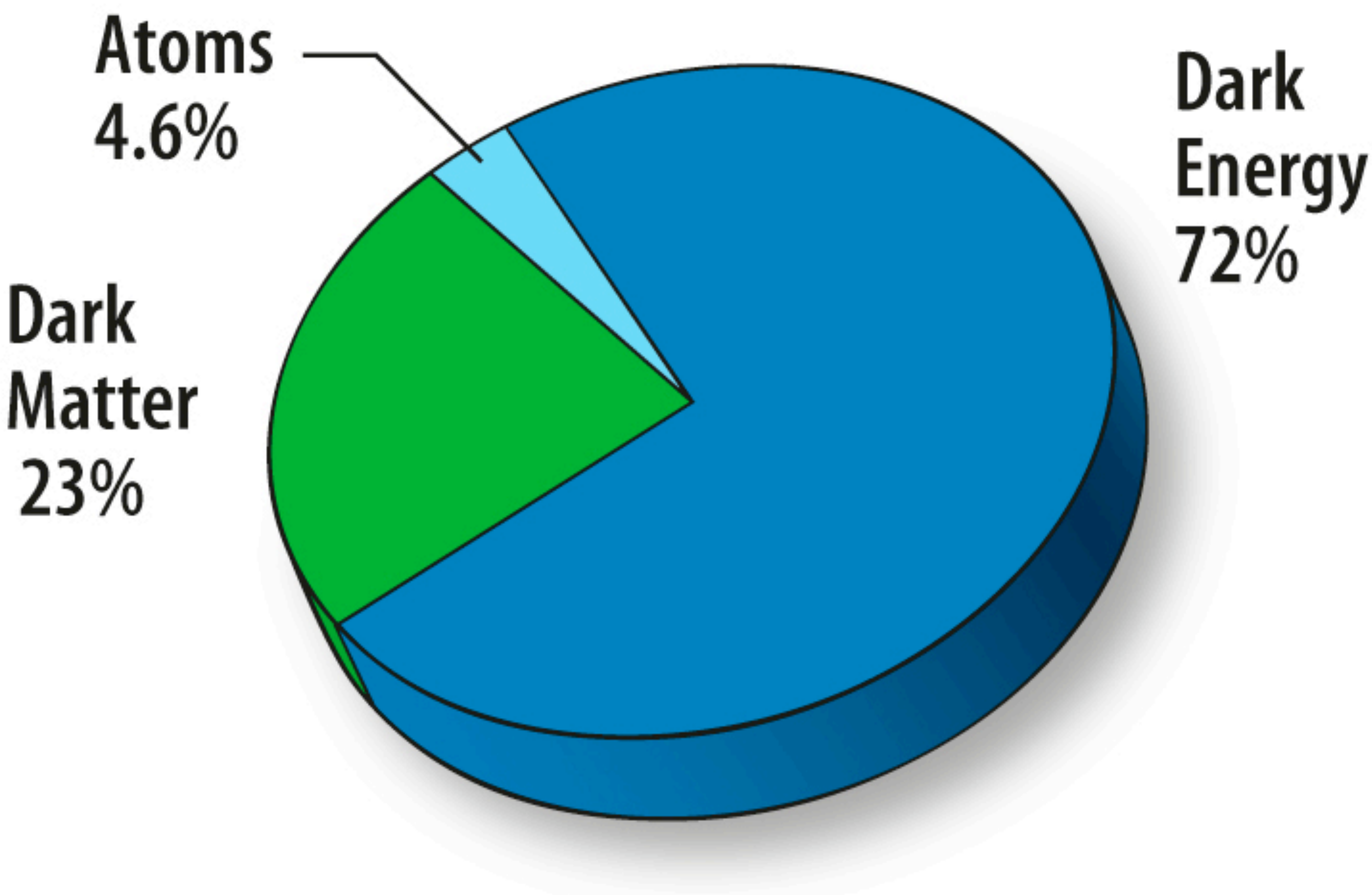
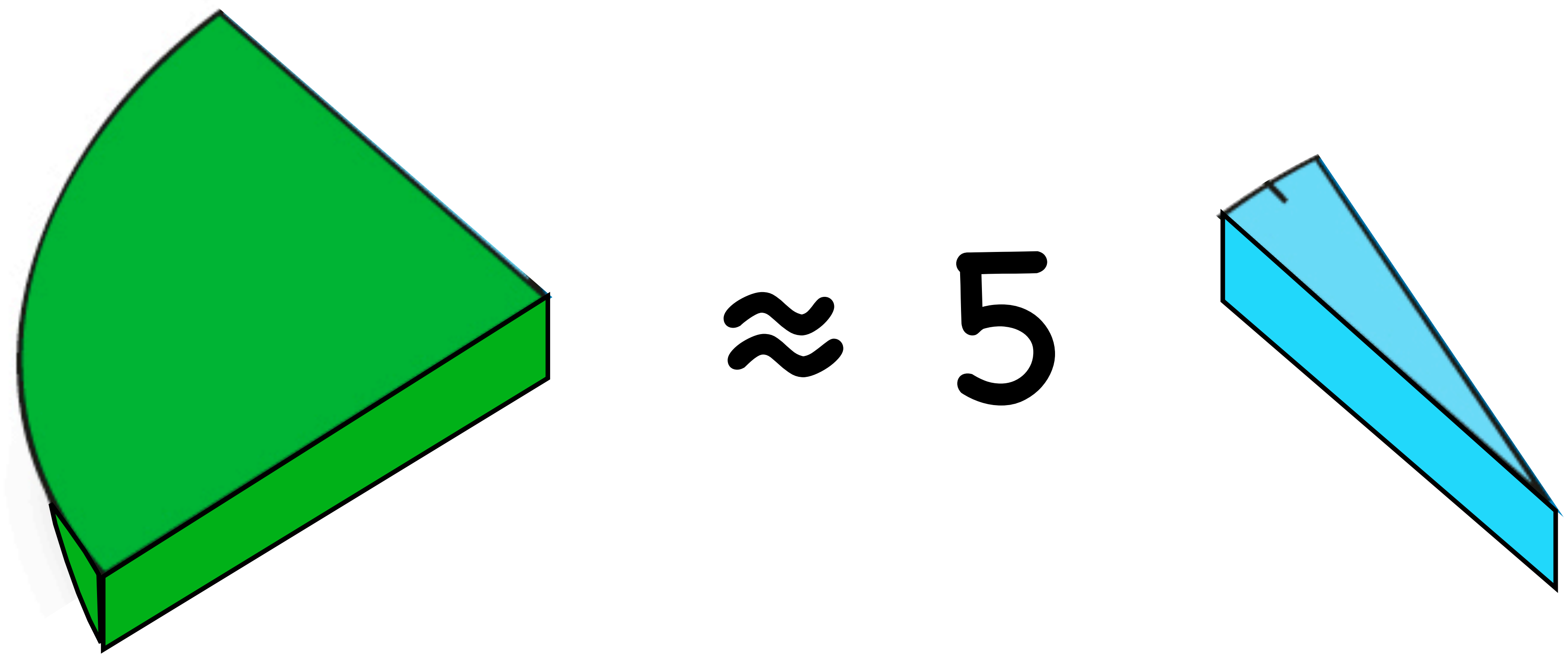
Energy Budget of Universe

(today)



WMAP 2009

Coincidence?



$$\rho_{\text{dark matter}} \approx 5\ \rho_{\text{baryon}}$$

Quirks

“Quirks”: New strongly interacting sector
with new fermions transforming
under (part of) the SM gauge group.

Kang, Luty

Not after “wacky phenomenology”, but instead
DM from new strongly interacting sector

GK, Roy, Terning, Zurek
0909.2034

Why?

Avoid difficulties of technicolor by not forcing the model to do everything.

Spectrum and some interactions perturbatively calculable (like heavy quarkonia...)

Abundance, detection (safer!), phenomenology can be qualitatively different from "vanilla DM"

See also
Alves, Behbahani, Schuster, Wacker;
Kaplan, Krnjaic, Rehermann, Wells

Technicolor	Luty Quirks	Quirky DM
SU(N) technicolor	SU(N) infracolor	SU(2) infracolor
$\Lambda \approx$ TeV	eV < Λ < TeV	$\Lambda \ll \langle H \rangle$
Chiral technifermions (massless)	Vector-like quirks (mass ≈ weak scale)	Chiral quirks (mass ≈ weak scale)
EWSB through TC condensate	EWSB through $\langle H \rangle$	EWSB through $\langle H \rangle$
Precision EW concern (for N,N_f large)	Precision EW totally safe	Precision EW ok (for N,N_f small)
Cosmo safe	Cosmo ok Λ > GeV less clear Λ < GeV	Cosmo ok Λ > 0.1 GeV less clear Λ < 0.1 GeV

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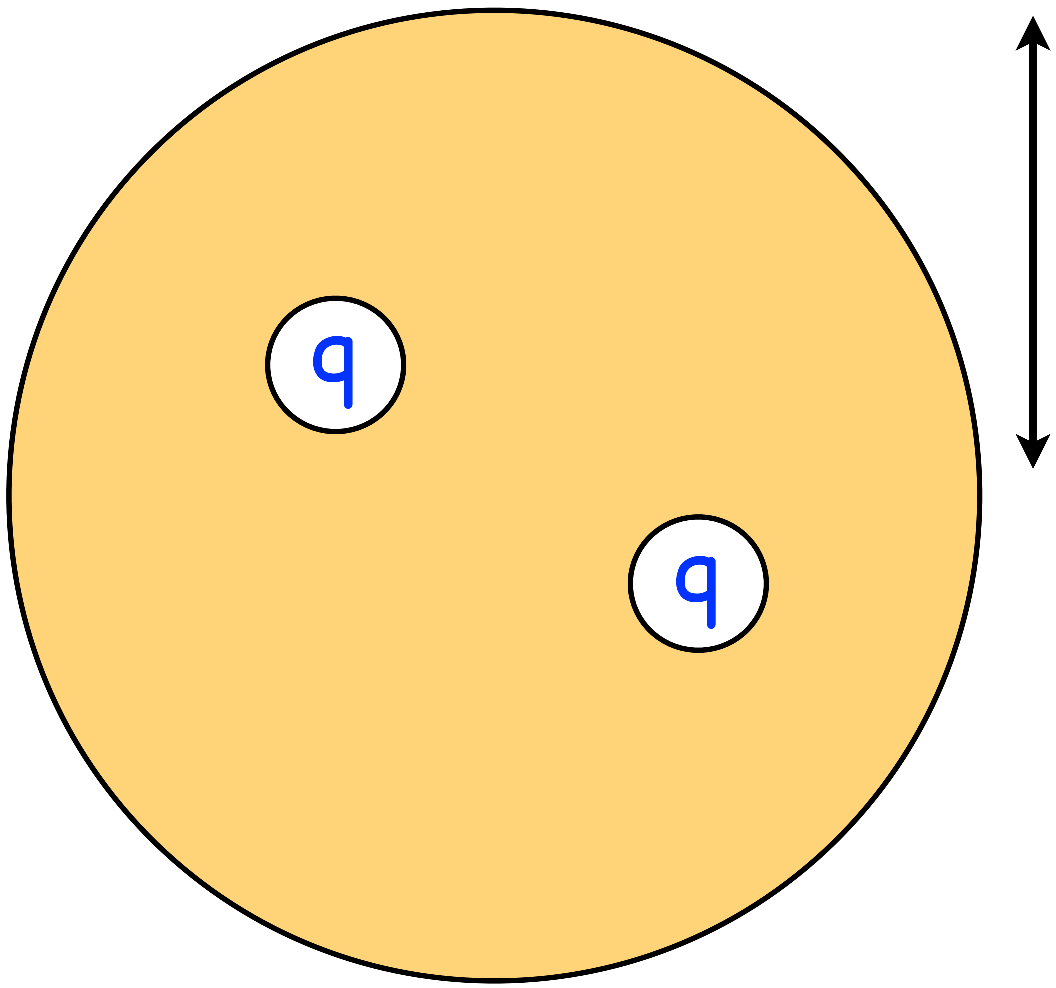
Quirky Dark Matter



$1/\Lambda_Q$

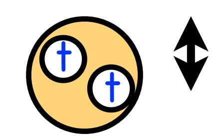
"quirkybaryon"

$\Lambda_Q \approx$ GeV

$m_q \approx$ 100-500 GeV

$M_{QB} \approx 2m_q$

"Technicolor"



$1/\Lambda_{TC}$

technibaryon

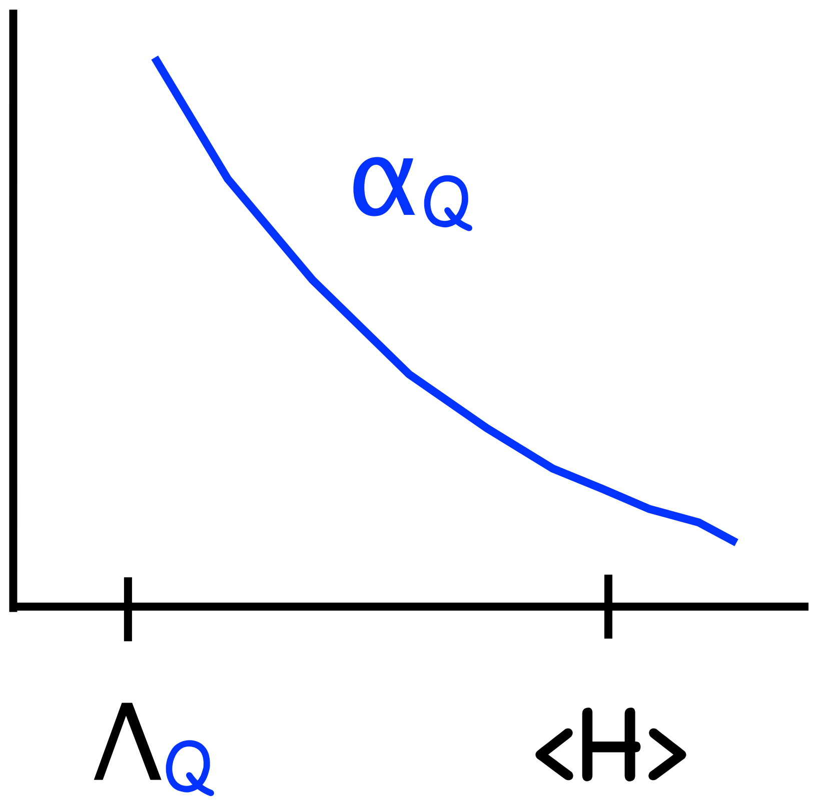
$\Lambda_{TC} \approx$ 1 TeV

$m_t = 0$

$M_{TB} \approx \Lambda_{TC}$

Field Content

	$SU(2)_Q \times$	$SU(2)_L \times$	$U(1)_Y \times$	$U(1)_{QB}$
Q	$\square$	$\square$	0	+1/2
u^c	$\square$	–	-1/2	-1/2
d^c	$\square$	–	+1/2	-1/2



$$L_{higgs} = \lambda_u H Q u^c + \lambda_d H^\dagger Q d^c$$

$\approx O(1)$

Baryon Stability

In SU(2), can write dim-3 gauge invariants (QQ) and (ud) which break $U(1)_{QB}$.

We simply require $U(1)_{QB}$ -- technically natural.

$U(1)_{QB}$ Anomalous?

$U(1)_{QB}$ is vector-like with respect to $SU(2)_Q$.

Hence, it is non-anomalous w.r.t. $SU(2)_Q$ (no "dark instanton" violation of $U(1)_{QB}$).

$U(1)_{QB}$ (like $U(1)_B$) is anomalous w.r.t. EW group.

It is precisely this fact that will allow EW sphalerons to (re)populate B,L,D numbers given some initial B-L and "B-D" numbers.

Quirky DM Spectroscopy

Use non-relativistic approximation; Dirac fermions decompose in (flavor,spin) space as

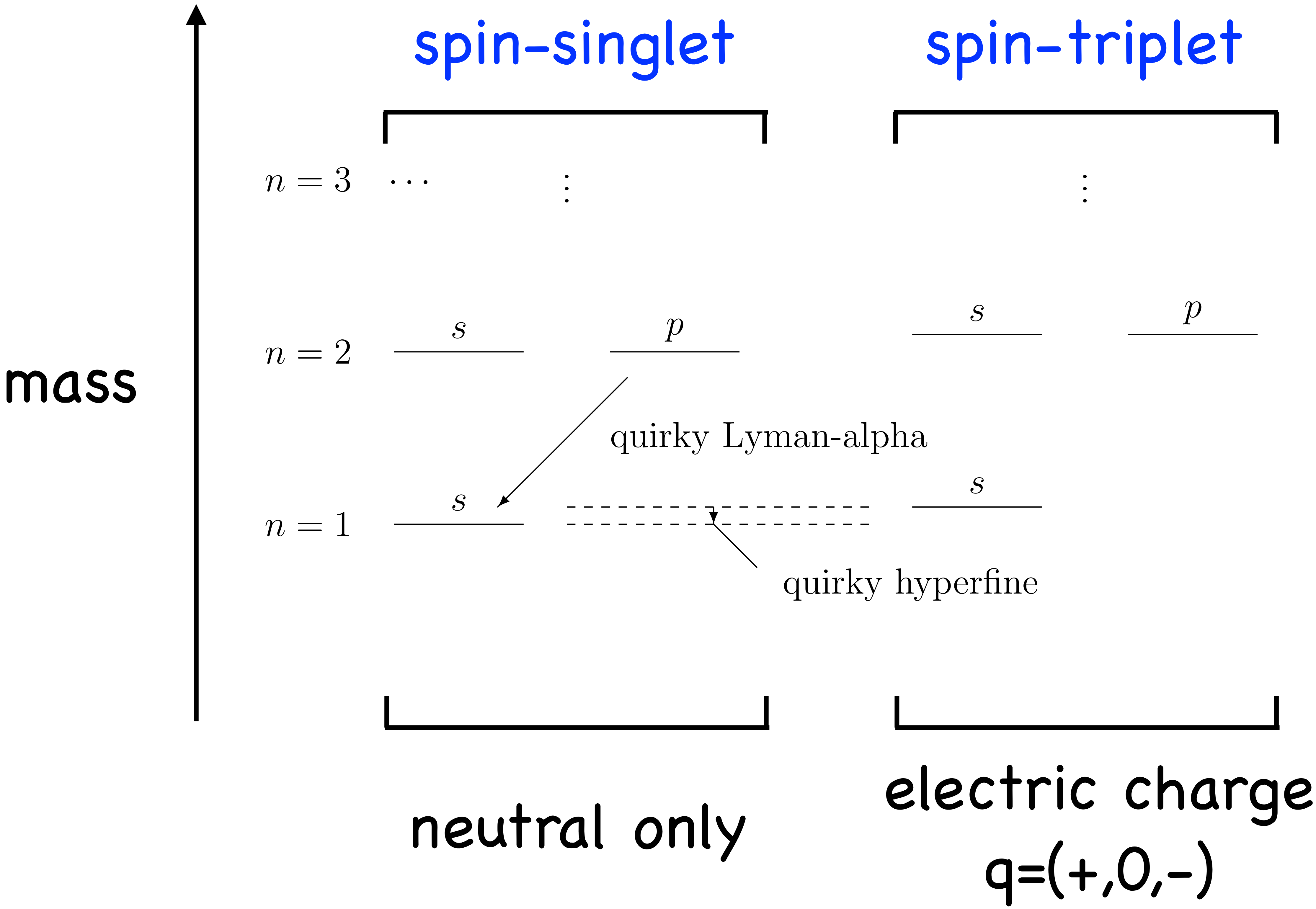
$$(2,2) \times (2,2) = (1_a,1_a) + (3_s,1_a) + (1_a,3_s) + (3_s,3_s)$$

Baryons -- the antisymmetric $SU(2)_Q$ contraction of identical particles, require antisymmetric wfn:

$(1_a,1_a)$ -> spin-singlet, flavor-singlet

$(3_s,3_s)$ -> spin-triplet, flavor-triplet

Quirky DM Spectroscopy



Lightest Neutral Baryon

Electric charge neutrality implies must have

$m_u \approx m_d$

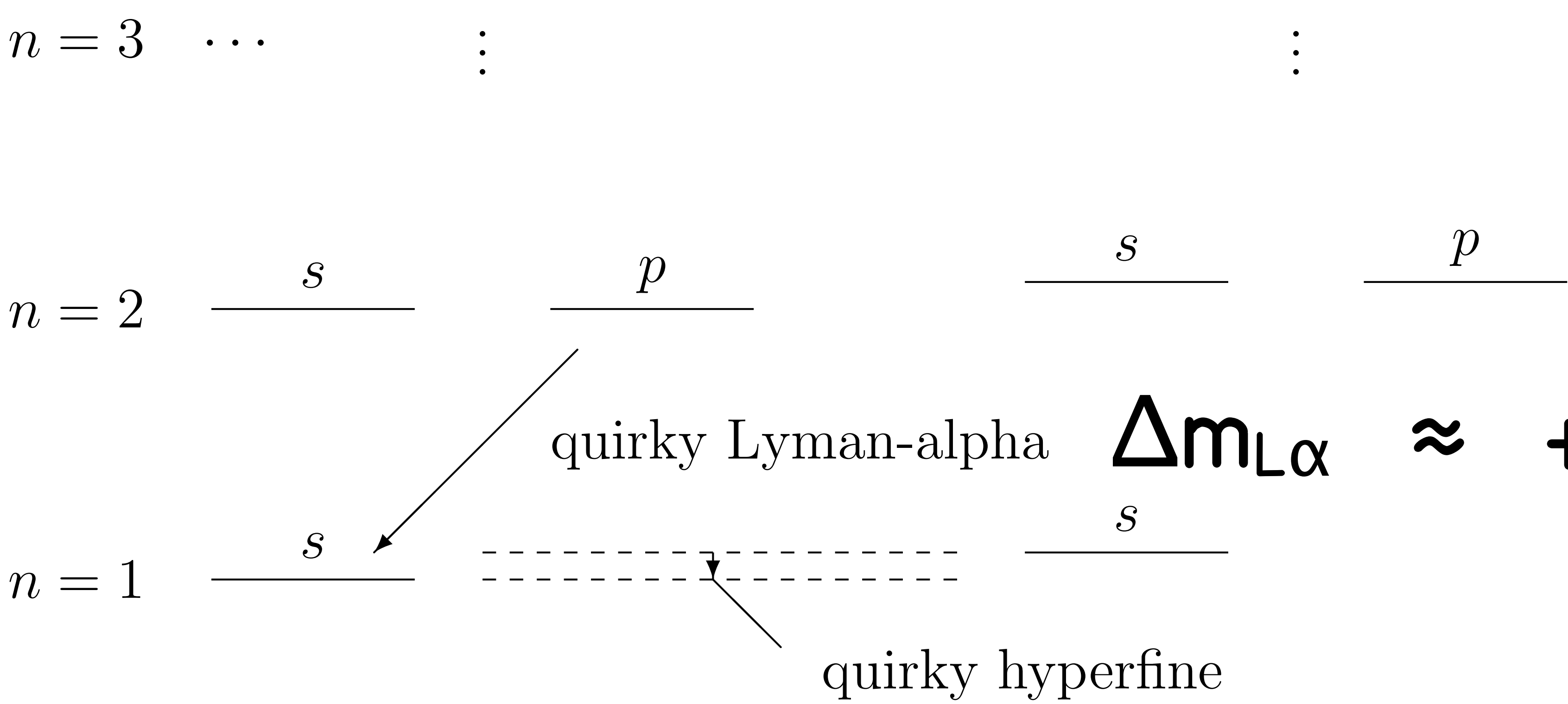
so that lightest baryon not made out of one (lightest) quirk.

(Impose "ud" parity --> $m_q = m_u = m_d$.)

Quirky DM Spectroscopy

$V(r) = -\bar{\alpha}(r)/r$

$\mu = m_q/2 \approx M_{QB}/4$



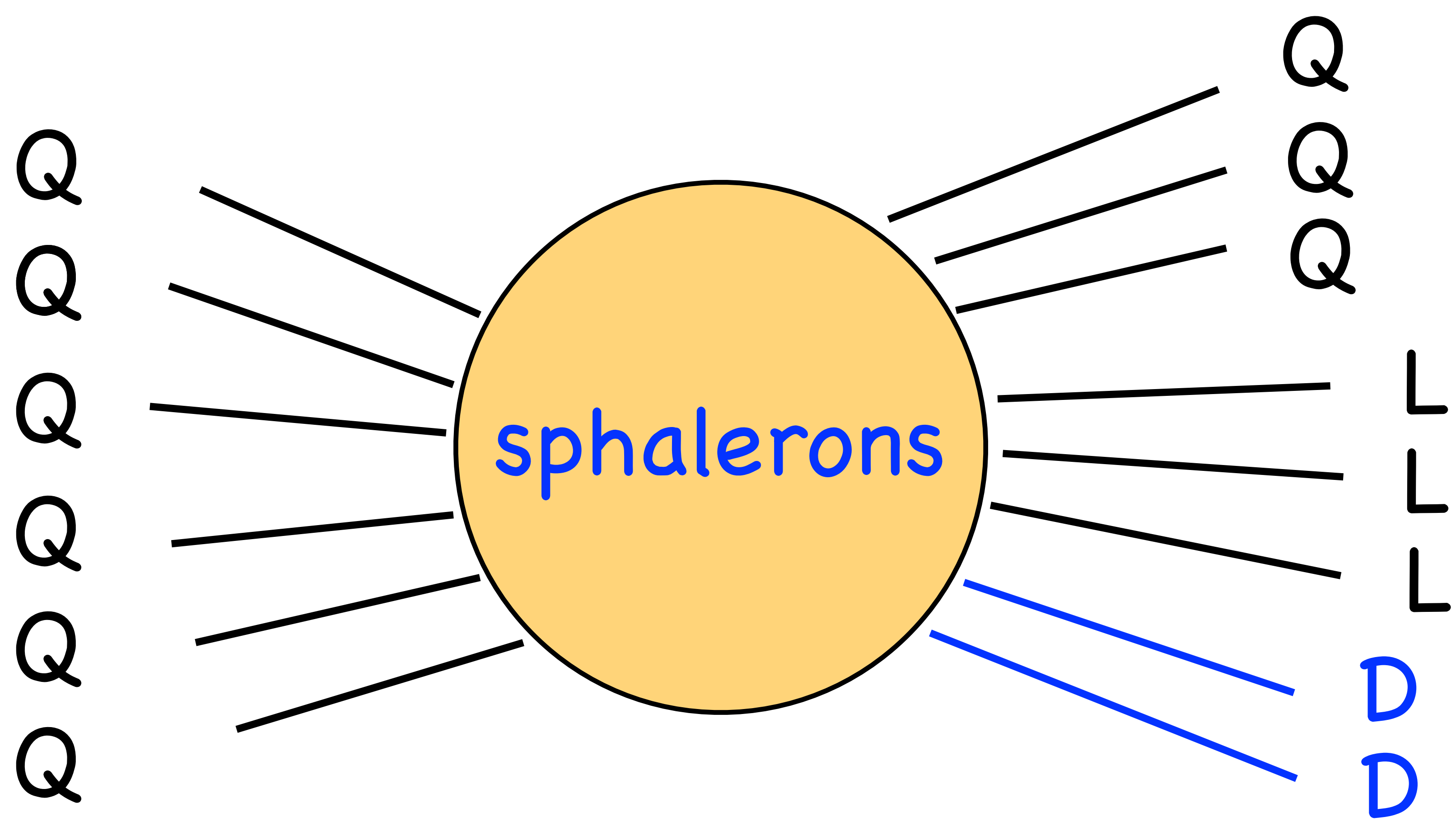
$\Delta m_{L\alpha} \approx + \bar{\alpha}(a)^2 \mu$

$\Delta m_{hf} \approx + \bar{\alpha}(a)^4 \mu$

at Bohr radius

Abundance

Barr, Chivukula, Farhi (1990) recognized



redistribute B,L,D number among electroweak doublets above and near the EW phase transition.

EW Sphalerons

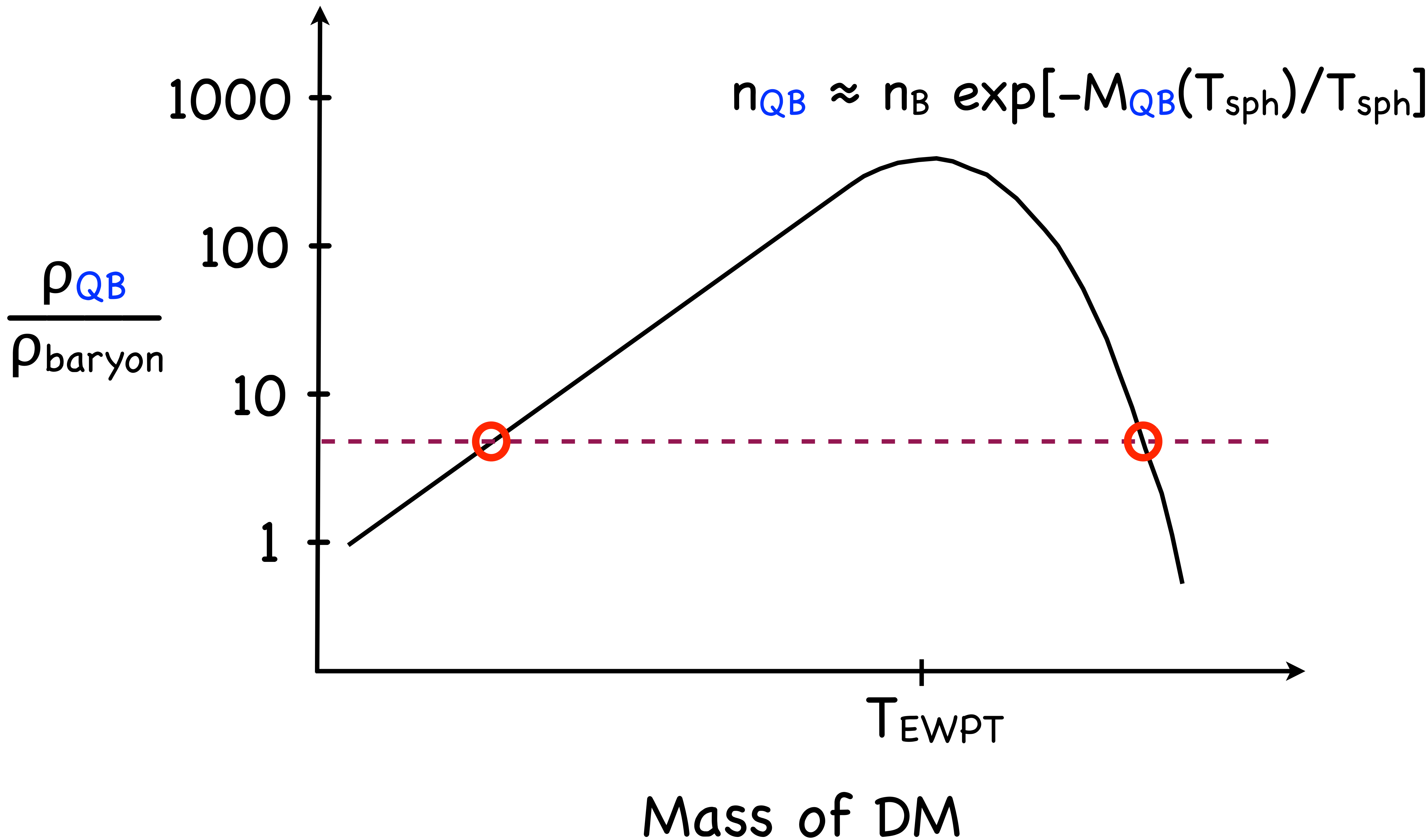
- SM: violate $U(1)_{B+L}$
- QDM: violate generalization $U(1)_{B+L+D/3}$

Leaves two anomaly-free invariants:

B-L ; B-3D

DB Kaplan

Asymmetric DM Abundance



Naturally get $\rho_{dark} \approx 5\ \rho_{baryon}$

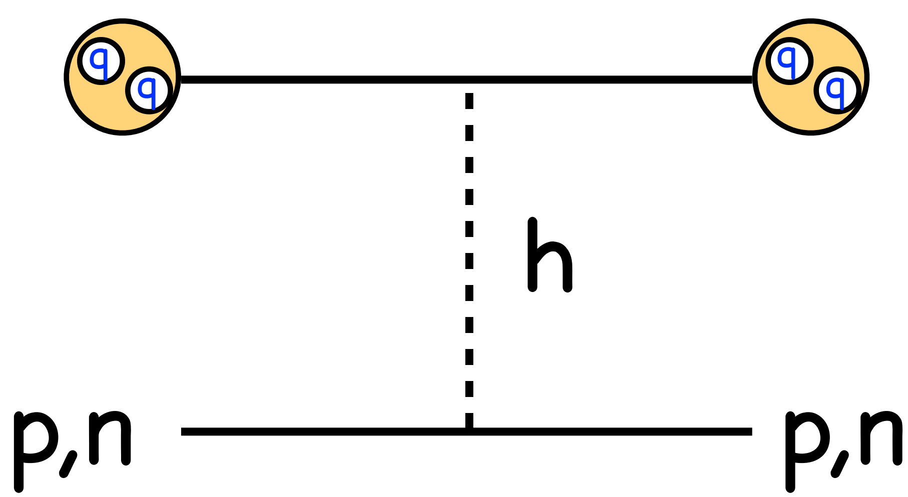
1

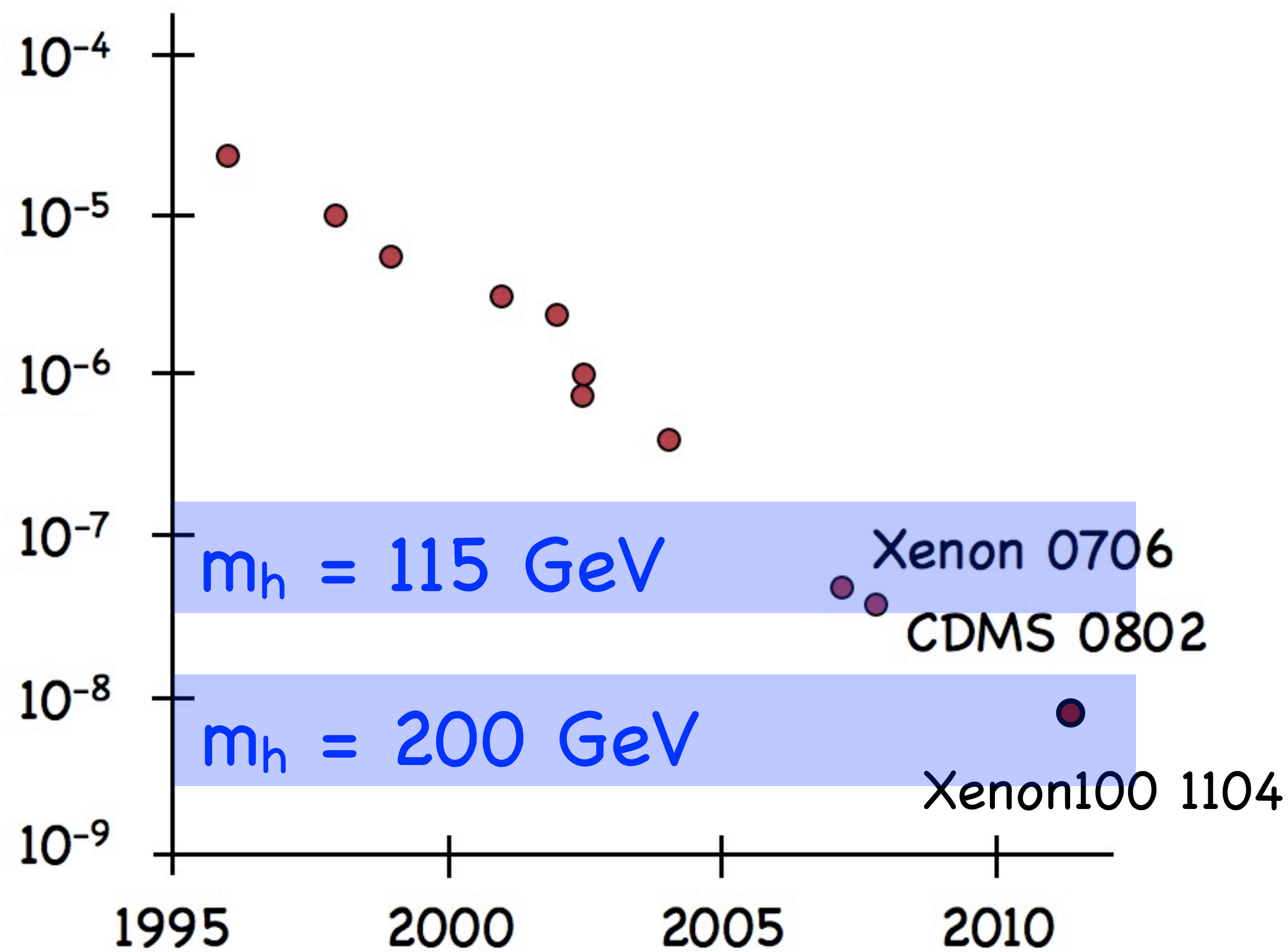
5 $\qquad \dfrac{\rho_{QB}}{\rho_{baryon}}$

25

Detection Strategies

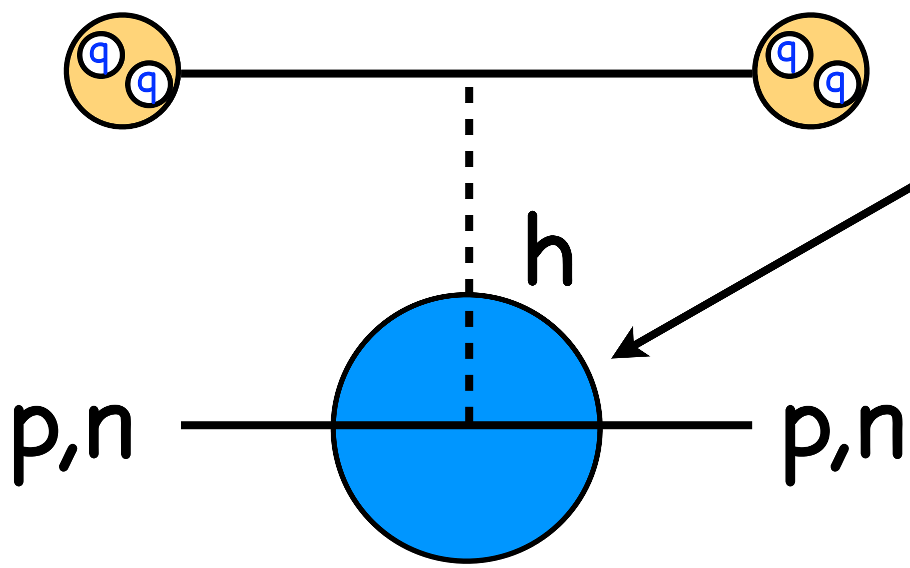
Direct Detection I





Completely determined by Higgs mass.

Direct Detection I



Lattice extraction of strange content direct impact

Completely determined by Higgs mass.

Direct Detection II

The charge radius

$$\frac{\varphi^{*}\varphi\ v_{\nu}\ \partial_{\mu}F^{\mu\nu}}{\Lambda^{2}}$$

vanishes due to ud-parity (here $A^{\mu} \to -A^{\mu}$).

This is important, since our estimate from direct detection bounds is: $r_D^{-2} \approx \Lambda^2 \;\; {\approx}{>} \;\; (500\ \mathrm{GeV})^2$

Direct Detection III

EM polarizability through:

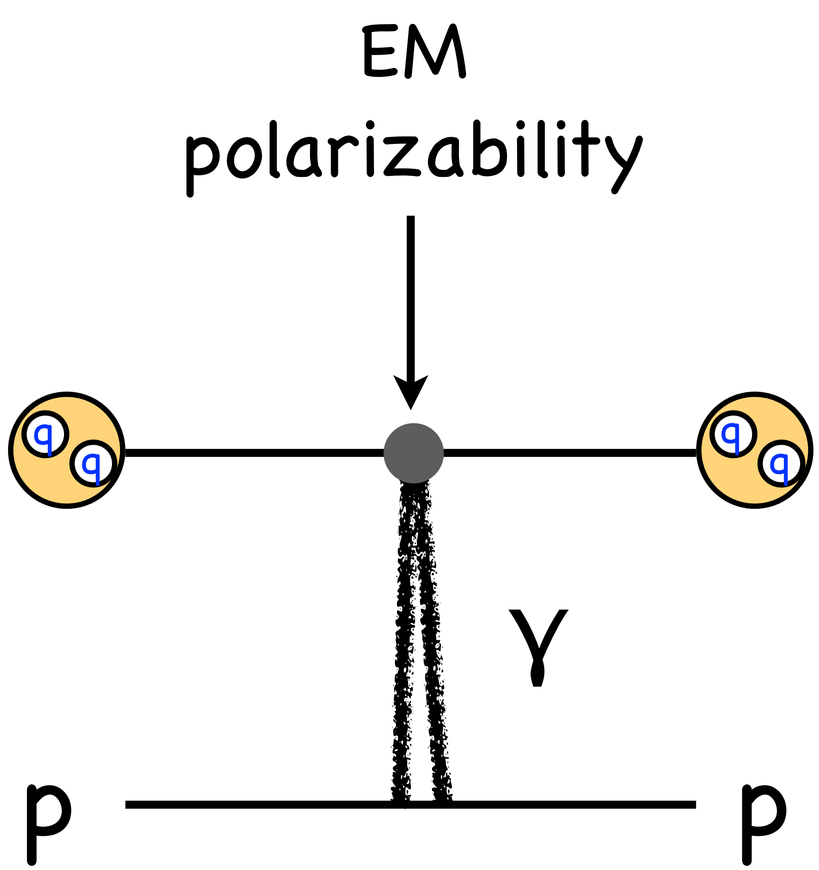
$$\frac{\varphi^*\varphi \; F_{\mu\nu} \, F^{\mu\nu}}{a^{-3}}$$

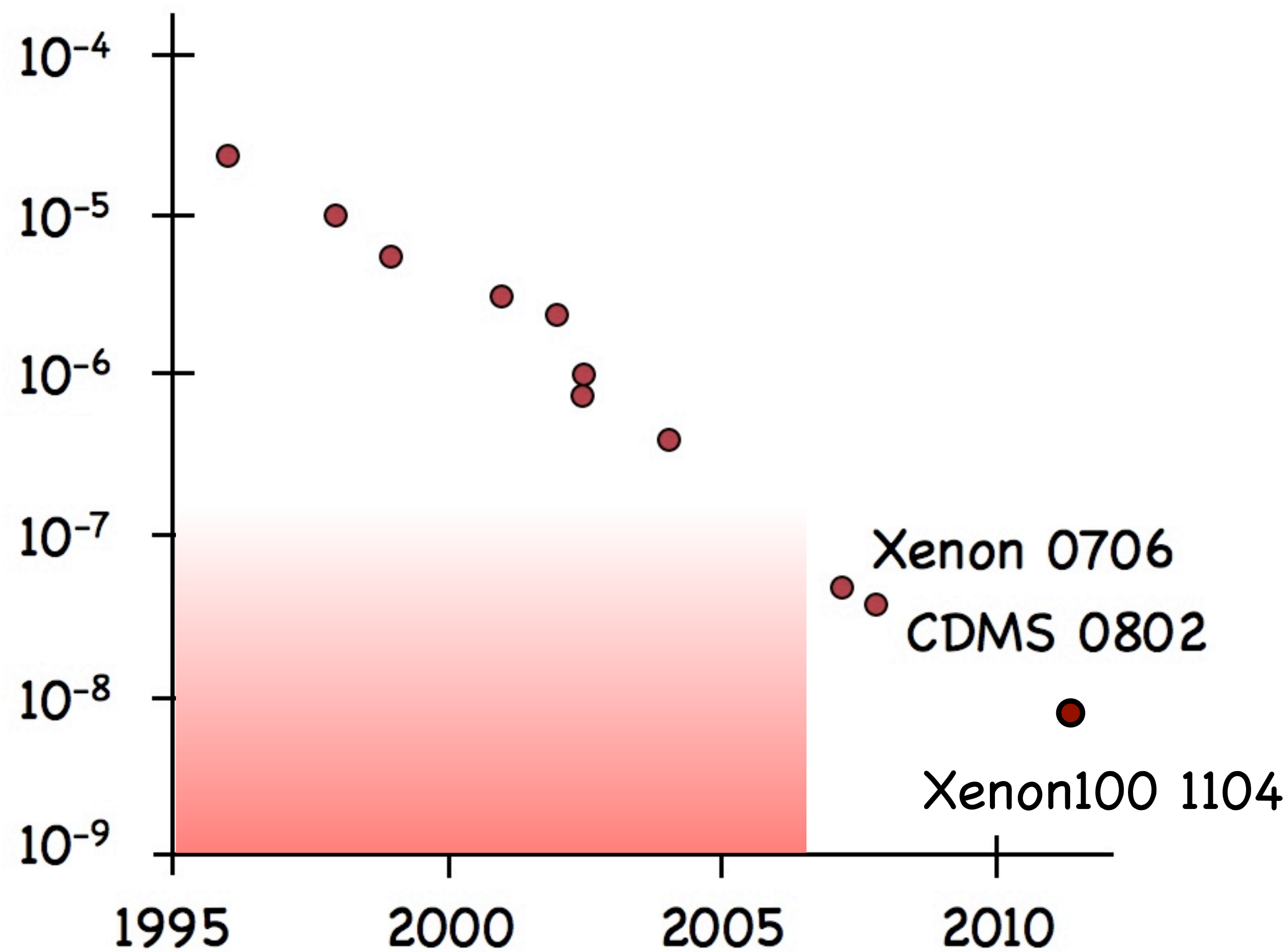
Using NR QM calculation of EM polarizability, obtain:

using Pospelov, ter Veldhius

$$\sigma_X(\text{Nucleus}) \approx \frac{Z^4 \; \alpha_{em}{}^2}{A^2} \left(\frac{\alpha_{em}}{\alpha_Q}\right)^2 \frac{\mu_r{}^2 \, r_{Nuc}{}^{-2}}{a^{-6}}$$

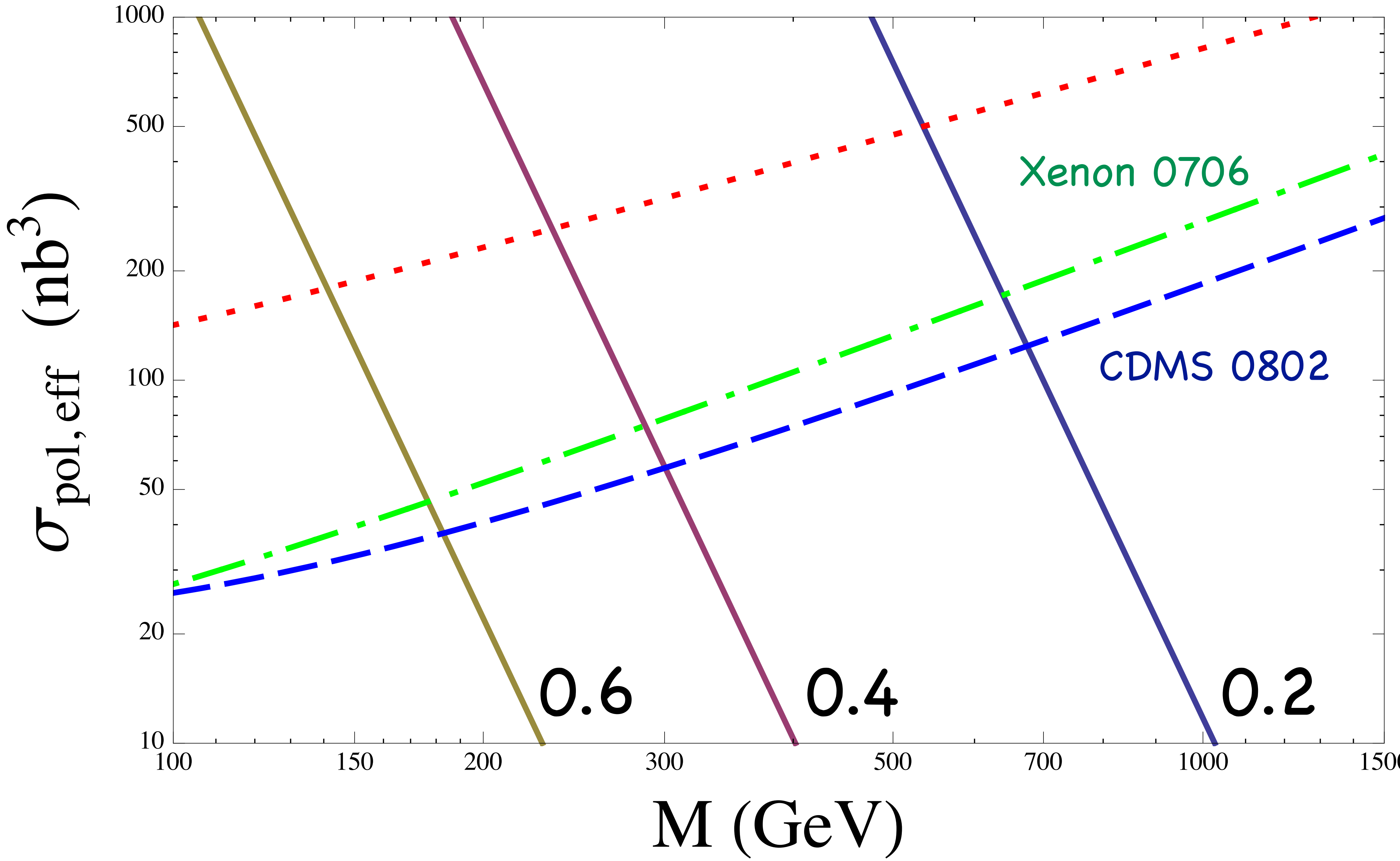
Direct Detection III





σ proportional to Z^4

Polarizability Bounds



$$\sigma_{\mathrm{pol,eff}} \quad = \quad \frac{r_0^2}{Z^4}\,\frac{1}{\mu(D,N)^2}\sigma(\mathrm{Nucleus})_{\mathrm{pol}}\ .$$

Indirect Detection I

If QB number exactly conserved, annihilation forbidden!

(if not, enter the realm of decaying dark matter)

Quirky Lyman-α; Quirky Hyperfine!

Search for dark lines
from γ-ray absorption!

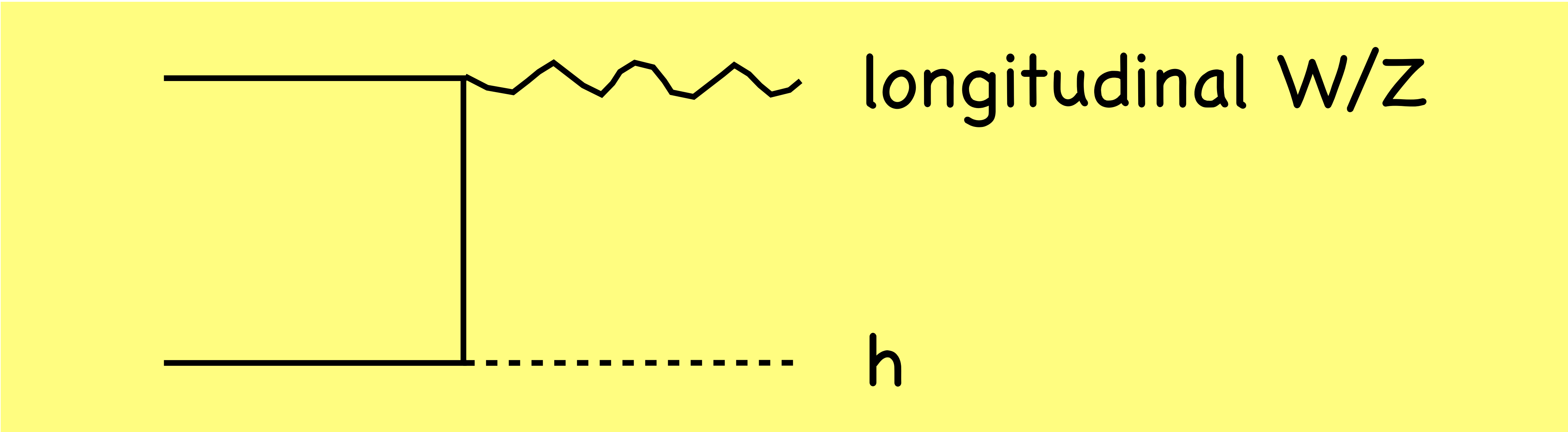
(Futuristic: need $\Delta E/E \lesssim 1\%$
and clusters/analysis techniques
to extract S/B)

typical transition $E_\gamma \approx 100$ MeV to 10 GeV

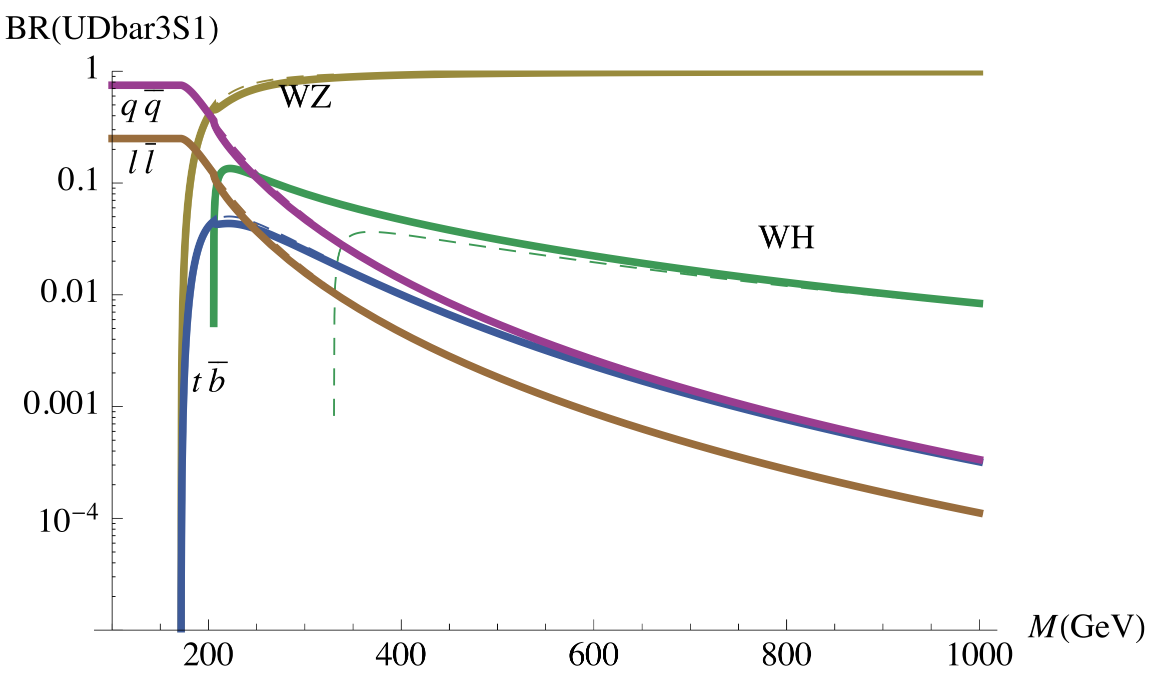
same signal, different model: Profumo, Sigurdson

LHC? Quirky Meson Decay Signals

In 1106.3101, Fok & I examined quirky meson decays:

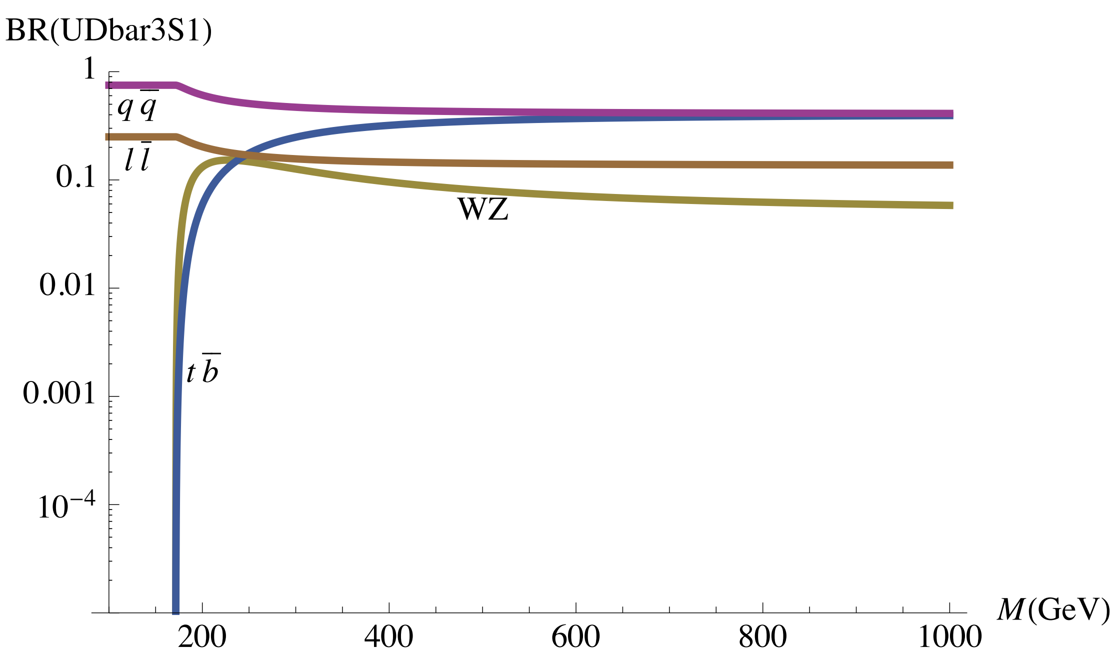


chiral



(b) $^3S_1$

vector-like



(a) $^3S_1$

Summary

- Quirky DM scalar baryon composite; direct detection through polarizability (Z^4!) and Higgs exchange now being tested

- $\rho_{QDM} \approx 5\, \rho_{matter}$ from asymmetry

- Novel collider signals of quirkonium (meson) decays to h/W/Z pairs due to chiral enhancement

- As we (re)approach strong coupling (technibaryons) better handle on interactions (charge radius, polarizability) vital to determine viability